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14. ABSTRACT This report documents activities to develop and equip a laboratory for robot mobility research and development. The laboratory includes mobile robots, testing systems, instrumentation, analysis tools, as well as test and analysis procedures. Robot mobility tests and analyses were conducted to confirm the facilities and procedures.						
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Intelligent Mobility Laboratory

Final Report

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1. Introduction

This document constitutes the Final Scientific and Technical Report, Data Item No. A0003, on contract DAAE07-01-C-L066 "Intelligent Mobility Laboratory." The report summarizes the objectives, activities, products and results of the contract effort.

The general objective of the contract was to provide engineering and material products for the TARDEC Robotics Mobility Laboratory (TRML) in its mission to develop, test and evaluate unmanned ground vehicles (UGVs) for the Army. The contract was to design, develop and demonstrate laboratory and field test and evaluation procedures and equipment addressing the specific needs of the TRML, including selected UGV subsystems as needed to represent baseline performance capabilities.

The specific activities and products under the contract are described in the remainder of the report. Section 2 summarizes the products and activities under the contract. These products included various analyses, tests, engineering drawings, and reports. Section 3 summarizes the specific items of laboratory equipment delivered under the contract.

2. Summary of Activities

The summary of activities is organized chronologically by calendar year.

2.1 Calendar-Year 2001

We held the kickoff meeting with TACOM contract and technical representatives. We agreed to take 90 days to coordinate with TARDEC research scientists and engineers to prioritize and detail focus intelligent mobility projects for the TARDEC Robotics Laboratory, and from this to define any significant changes to the laboratory equipment list. These changes, if any, would be prepared in proposed modification to the contract. Tier 1 topics for definition of metrics and test methods were: (1) intrinsic mobility; (2) sensing and perception; and (3) diving and control. Tier 2 topics for definition of metrics and test methods were: (4) operator control; (5) route planning; and (6) teleoperation.

We held coordination meetings with TARDEC scientists and engineers to refine TARDEC robotics laboratory project goals, and the associated laboratory facilities, integration and validation requirements. We fabricated prototype terrain and obstacle modules for the surrogate terrain and obstacle test course. We prepared a working draft of intelligent mobility metrics and assessment methods. We reviewed relative merits of alternative terrain measurement methods, including cone penetrometers and bevameters, with Dr. Gerhart, Dr. Sloss, and faculty of the Michigan Technological University Keweenaw Research Center.

We prepared briefing charts describing the objectives, methods and anticipated products of the TARDEC Robotics Laboratory for TARDEC's presentation to the National Research Council in September. We held coordination meetings with TARDEC scientists and engineers to refine TARDEC robotics laboratory project goals, and the

associated laboratory facilities, integration and validation requirements. Alternative systems and components for equipping the laboratory were reviewed in detail. We fabricated additional prototype terrain and obstacle modules fabricated for the surrogate terrain and obstacle test course. We prepared a working draft of report on "Metrics for Intelligent Mobility" (Task 1) (document transmitted per contract requirement).

We delivered initial purchases of TRML laboratory equipment. We participated in coordination meetings held with TARDEC scientists and engineers and the project team from Utah State University working on the ODIS and T4 robotic vehicles. We prepared briefing charts on concepts for security inspection robots.

We met with TARDEC engineers and scientists to discuss sketch-based mission assignment for operator-robot interaction using a hand-held device. We subsequently provided a two-page description of robot behaviors and processing to follow the sketched path. The approach assumes that the robot has directional range sensors (e.g., a sonar ring) and wheel encoders. The essence of the approach is to derive directional sketch-correction factors from the ratios of the actual directional ranges and the sketch ranges, then use these factors determine the projection of the sketch path onto the real world for the next short segment of the sketch path.

We designed and fabricated a prototype six-degree-of-freedom (6DOF) damped spring system to for passive coupling to enable two vehicles to operate in tandem (snake) as an articulated vehicle. A demonstration system was constructed with two small skid-steer vehicles. The vehicle wheel diameter was 6.5 inches, but the coupled system demonstrated the ability to climb a 9.5 inch vertical step.

We delivered laboratory equipment for the TRML.

2.2 Calendar-Year 2002

We held a meeting with a representative of the company that supplied the mini-FLIR to demonstrate the mini-FLIR and to demonstrate an alternative to the Agema FLIR. We demonstrated tandem vehicles linked with a 6DOF sprung-and-damped coupling at TARDEC.

We coordinated laboratory benches, test stands and related furnishings. We held coordination planning meetings with TARDEC related to preparations for the May Joint Robotics Program (JRP) meeting. We demonstrated operation of the Palm IR Pro and the Raytheon mini-FLIR.

We prepared skid-steer and Ackermann-steer tandem vehicles for mobility enhancement evaluation. We prepared "snap-on" video capture and transmission units for small UGVs. We prepared five posters synopsizing robotics research and development activities. We authored a joint paper with TARDEC, presented at the TARDEC-sponsored UGV Conference at the SPIE AeroSense Symposium in Orlando, FL.

We prepared an indoor obstacle course matched to the sensing field of the TARDEC motion tracking system for the JRP meeting. We prepared and delivered three vehicles capable of tandem operation with suspension linkages, capable of inverted operation with automatic correction to stay on course despite roll-over. Each vehicle is programmable for head, body, or tail positions in the snake. We participated in the TRML demonstrations at the JRP meeting.

We participated in meetings with TARDEC scientists and Automotive Research Consortium (ARC) researchers for collaborative modeling and demonstration of tandem robot operation.

We provided materiel support for the ODIS Limited Operational Experiment at Ft. Leonard Wood.

2.3 Calendar-Year 2003

We conducted research and engineering analyses for the ODIS underbody inspection vehicle. We defined requirements and assessed available methods for image processing algorithms and related imaging work on ODIS. We developed plans for UGV mobility and survivability research with TARDEC scientists pursuant to Army Science Board review at TARDEC. We researched active lighting, articulated sensor deployment, sunlight-readable displays, and landmark navigation software for ODIS inspection and navigation tasks.

We fabricated and delivered a mock-up of a “disrupter” to demonstrate the potential use of a small, omni-directional robot (specifically, ODIS) to employ a disrupter to defeat a suspected “briefcase bomb.” The disrupter consisted of an adjustable mounting, and the electronics to emit a laser dot and modulated IR data stream. The briefcase target had an electronic sensor to detect the data stream and respond by flashing LED lights. We coordinated with TARDEC personnel regarding requirements and solutions for measuring shock and vibration on ODIS created when firing a disrupter, and provided the necessary equipment. We prepared materials for the TARDEC demonstrations at the Force Protection Equipment Demonstration (FPED) conference.

We developed and began testing software to log differential Global Positioning System (DGPS) data at 10Hz, with simultaneous logging of 6DOF inertial sensor data at 100 Hz, and 4 A/D channels at 100 Hz (from LabJack A/D converter).

We developed equipment and procedures to collect UGV terrain trafficability data, and conducted data collections at Toole Army Depot and at Fort Indiantown Gap in conjunction with Demo III experiments. We developed, demonstrated and documented methods to estimate two key mobility-performance metrics (maximum speed and drawbar pull) from the vehicle-terrain interaction data. The primary instrumentation was an instrumented trailer to measure rolling and sliding resistance, and ground disturbance. Supplemental instrumentation included a Clegg impact hammer and a cone penetrometer to measure dynamic and quasi-static soil stiffness.

We outfitted a Pioneer 2AT mobile robot with a high-accuracy inertial navigation system and software for the DREX symposium. We provided on site assistance in the demonstration and using the robot.

2.4 Calendar-Year 2004

We researched and defined requirements for real-time video digitization hardware and software, and delivered said items. We worked with TARDEC scientists to define the specific requirements for noncontact (remote) monitoring and surveillance, including lenses, scopes, sights, mounts and polarization filters.

We researched digital video transmission options as an alternative to the current system with two radio links (analog NTSC robot-to-base video transmission, with parallel low-speed digital radio for base-to-robot data transmission). The drawbacks and limitations of the current system are that it requires two radio systems; there is no mechanism to transmit additional data from the robot to the base (although it is possible to modulate the audio sideband) and the quality of the video is limited by the NTSC format. Up to now, wireless digital protocols have not had adequate latency or frame rate. Dedicated wireless internet cameras had latency in excess of one second, with refresh at three frames per second. This has been (not adequate for teleoperation). Working with the low-level video and internet protocols, we were able to achieve less than 0.25-second latency and 15-fames-per-second update (adequate for teleoperation) using standard 802.11b wireless intranet. Lower latency and higher frame rates or larger image size should be possible with the new 802.11g equipment. The advantages of wireless internet are that digital images are transmitted without NTSC degradation, image resolution can be selected (higher resolution for inspection, lower for driving), only one radio system is required, and additional data channels can be added. [900 MHz RS-232 and USB data radios were not suitable for video transmission. Even the higher speed 19.2 baud radios will not achieve adequate frame rates for teleoperation.]

We identified a vendor of a low-profile retractable mast suitable for integrating onto the ODIS robot without impairing underbody access, and yet capable of elevating the sensors to 5 feet (the mast vendor is integrating the unit on an ODIS robot provided by TARDEC).

We began test and evaluation planning for TARDEC small robots with sensors on arms and/or retractable masts for total vehicle inspection. The conceptual design extended the current TARDEC ODIS underbody inspection robot to enable operators to look into driver/passenger compartments and truck beds. Additional applications, beyond military checkpoints, include truck inspection at border crossings, on board inspection container ships docking at US ports, and container trucks exiting from US ports. The working environments and mission priorities were analyzed to determine the potentially appropriate development and testing issues with respect to sensors, operator interfaces, mobility, and autonomous behavior.

We worked with the supplier integrating the retractable mast on the ODIS unit (integration prototype) to resolve technical issues in the integration. We detailed scenarios for test and demonstration of ODIS with mast-mounted sensors.

We researched approaches to enable the ODIS operator to switch views between two cameras, one on the robot and one fixed in overwatch positions. Candidate hardware consisted of a 4-channel 4 GHz video receiver with "push-button" channel selection, and video camera-transmitter pairs operating on the same channels.

2.5 Calendar Year 2005

We conducted research, development, test and evaluation of alternative motorized mast systems for camera deployment on small robots. We researched alternative presentation technologies for use in the TRML.

We shot video footage of the ODIS robot being used for vehicle inspection, finalized the script, and edited the video footage and footage from the Middle East into a coherent video. We defined dual-use application scenarios of TARDEC physical security robots for homeland security and homeland defense, relative to their standards and situations. We produced, packaged and delivered CDs with the video documentary of the TRML vehicle inspection robots for force protection and security.

We developed briefing materials on intelligent mobility programs for presentation at the TARDEC/NAC Intelligent Vehicle Symposium. We produced a physical model of a small UGV using hybrid locomotion combining elements of anthropomorphic design and more traditional wheel/track running gear and suspensions. We demonstrated self-righting ability, self-stabilized obstacle crossing, and static stability in obstacle crossing.

We worked with TARDEC scientists to define and document RDT&E priorities for small UGVs for force protection. We participated in technical meetings with the Wayne State University (WSU) group under contract to TARDEC to develop and integrate an explosive trace/vapor detector for the TARDEC ODIS robot. We prepared a summary of TARDEC robotics R&D addressing the vehicle-borne improvised explosive device (VB-IED) threat for the National Automotive Center, responding to a request from the Senate.

We refurbished electronics, sensors and other equipment in use at the TRML.

We performed initial systems engineering and analysis pertaining to integrating an explosive trace/vapor detection sensor with the ODIS vehicle inspection robot, a mast or arm, and such sensors as required to position the explosives detector. Initial systems engineering focused on establishing the deployment constraints and requirements of explosive trace/vapor detector technologies, threat characterization, workspace requirements for vehicle inspection at checkpoints, and search time and accuracy goals for military checkpoints. We surveyed potential detector, vapor collector and arm technologies.

2.6 Calendar-Year 2006

We prepared a report analyzing the capabilities and performance requirements for robot-assisted vehicle inspection at checkpoints. The paper reviewed the tactics, techniques and procedures to interdict VBIED. It presents an operational concept for robotic vehicle inspection within this framework, and identifies needed capabilities. It reviewed the technologies currently available to meet these needs, and summarized the immediate potential and R&D challenges for effective VBIED inspection robots. The paper was being coordinated with TARDEC personnel. The analysis and conclusions documented in the paper provided guidelines for selection, development and testing for inspection robot subsystems (camera, robotic arm, mobility, operator situation awareness, etc.).

We defined preliminary test plans to assess teleoperation to deploy explosive detection sensors with the ODIS robot, including requirements for positions with the ODIS base and an articulated arm.

We completed a paper on robotic systems for vehicle-borne contraband detection, in coordination with TARDEC co-authors. The paper was presented at the TARDEC-sponsored Unmanned Ground Vehicle Conference, of the SPIE Defense and Survivability Symposium.

We coordinated with Wayne State University on basic teleoperation testing for robotic deployment of an explosive vapor detection sensor on ODIS. We identified candidate augmented teleoperation methods.

We designed and fabricated a low-cost, rugged, modular, scaleable robotic arm, and demonstrated the arm at TARDEC. The design concept is essentially a scaled-down version of the hydraulic excavator arms on construction equipment. The prototype arm had two 30-inch arms for a total 60-inch reach. It had 135 degrees of motion at the "shoulder" joint and 180 degrees of motion at the shoulder joint. The collapsed height of the prototype was 9 inches. Its lift was in excess of 50 pounds at the end of the arm.

The design has two 30-inch arms. The design uses automotive aftermarket linear actuators instead of hydraulic actuators. The actuators are available with stroke lengths from 4 to 36 inches, 12/24/36 VDC operation, and 250, 750 or 1,500 pounds dynamic load. We selected a 12 VDC linear actuator with 250 pounds dynamic load, 8-inch stroke and 16-inch total length when withdrawn. We are controlling the actuators with a dual forward/reverse speed controller. The speed controller takes standard PWM servo input and thus is conveniently controlled from either an R/C radio receiver or an RS232 PWM servo controller board. The PWM servo controller board can be connected to an on-board micro-computer or a PC, or to a remote OCU via a radio modem or an RS232-to-802.11b wireless interface.

We produced engineering drawings for modified ODIS wheel assemblies for enhanced mobility on rough terrain. We fabricated and delivered the wheel assemblies for two enhanced mobility ODIS-T3 robots.

3. Laboratory Equipment

The Laboratory Equipment List, (Attachment 1 to Section J) per mod P00001, is presented in figure 1. The items of equipment that were delivered are then listed, according to the Laboratory Equipment List organization.

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MODNAME P00001	
ATTACH ID Attachment 001	
PAGE 1	
LABORATORY EQUIPMENT LIST (Attachment 1 to Section J)	
1.	LIGHTING AND SURROGATE TERRAIN AND OBSTACLES A. 425 square foot of modular, reconfigurable surrogate terrain and obstacles including structural features (ie include soil, grass, bark, roots and overhangs), surface characteristics (ie include bumps, artificial turf, high- and low-friction surfaces), and perception obstructions (ie include synthetic ground cover, shrubs and foliage). B. 1 stage lighting system, including light stands, and control console
2.	MOBILE ROBOT PLATFORMS A. 2 middle-weight (between 15 and 100 lb gross vehicle weight) all-terrain mobile robots complete with all hardware and software necessary for wireless remote operation. B. 3 light-weight (under 15 lb gross vehicle weight) mobile robots complete with all hardware and software necessary for wireless remote operation for use on level surfaces. C. Microcontrollers, servos, drivers, actuators, radio interfaces and other components as necessary to construct and test 2 mobile robots with different locomotion and control mechanisms.
3.	ON-BOARD INSTRUMENTATION A. Surveillance camera systems for remote tele-operation of the mobile robots. B. Inertial sensors (accelerometers and rate gyros) to record vehicle dynamics. C. Sonar sensors and bumpers to detect obstacles. D. Current meters and voltmeters. E. Global Positioning System (GPS). F. Other on-board sensors as deemed necessary. G. On-board data acquisition and logging and/or wireless transmission to off-board data logging.
4.	OFF-BOARD INSTRUMENTATION A. Force and torque measurement system with PC link. B. Balistometer and omnistilometer system with PC link. C. Core processor and complementary telecommunications equipment, instruments. D. 2 data acquisition and logging computers with A/D conversion and wireless communications for in lab and mobile use.
5.	DATA ANALYSIS, SIMULATION AND VISUALIZATION COMPUTER SYSTEMS A. Software packages for modeling, simulation and analysis of vehicle dynamics and functioning of robot controls. B. Virtual reality human interface hardware and software for tele-presence and tele-education for research and experiments including visual and kinesthetic feedback.

Fig. 1: Laboratory Equipment List

3.1 Lighting and Surrogate Terrain and Obstacles

We delivered a system of modular surrogate terrain and obstacles and a lighting system. The design and selection of the specific items were coordinated with the TARDEC engineers and scientists who would be using the equipment.

The modular terrain base consisted of 8-foot by 4-foot plates of reinforced pegboard with quarter-inch holes on a one-inch grid. The surrogate obstacles had pins fitting into the holes in the base plates so that obstacles could be positioned precisely, would be fixed in place, could be reconstructed, and so that alternate configurations could put alternate obstacles in the same locations. Braces connecting adjacent plates used the same mechanism. The plates could be configured in any pattern that consisted of rectangles with 2:1 aspect ratio. Due to limitations in the space available at the TARDEC Robotics

Mobility Laboratory for the surrogate terrain, the Government requested that only eight plates (256 square feet) be delivered.

Surrogate obstacles were engineered so that they could be fixed in position on the surrogate terrain base plates or to each other to make walls, stairs, gaps, ramps, overhangs and other geometric configurations. The following surrogate obstacles were delivered:

- Ten concrete spherical sections, with 4, 8 and 12 inch diameters and one-quarter and one-half sphere extent;
- Ten rectangular and triangular prism solids of different proportions at 2, 4, 8 and 12 inch minimum width; and
- A variety of artificial turf, vegetation, shrubs and foliage at different heights and traction coefficients.

We delivered a lighting system consisting of a 3700 lumen Proxima computer projector capable of dual use as either as a stage lighting source with programmable color and/or patterns, or as an auditorium presentation system. The projector has an embedded display console and a remote control for display console, and computer interface. We delivered a wall mounting system.

3.2 Mobile Robot Platforms

We delivered several different classes of mobile robot platforms. The specific items were coordinated with the TARDEC engineers and scientists who would be using the equipment.

We delivered 2 Pioneer 2AT ("All Terrain") middle-weight mobile robots, each weighing approximately 50 pounds. The Pioneer 2AT robots were delivered with all hardware and software necessary for wireless remote operation. These robots had 4-wheel drive, no suspension, and differential ("skid") steering.

We delivered 3 Koloa light-weight robots, each weighing approximately 5 pounds. Each of these 6 wheeled robots was delivered complete with all hardware and software necessary for wireless remote operation. These robots had all-wheel drive, no suspension, and differential ("skid") steering.

We delivered and integrated microcontrollers, servos, drives, actuators, radio interfaces, and mechanical components for three mobile robots. The three robots each could be operated independently. The individual robots had 4-wheel drive, no suspension, and differential ("skid") steering. The robots had mechanical linkage and control logic such that any two robots could be configured into a single, articulated 8-wheel robot, or all three could be configured into a single robot with two articulations and 12 wheels. This provided a three different locomotion and control systems. The articulated linkages were spring, so in the tandem configurations the robots had a suspension in the form of the body articulation. They were demonstrated at the JRP meeting held at TARDEC.

We delivered microcontrollers, servos, drives, actuators, radio interfaces, and mechanical components for two high-speed mobile robots in the 25-pound weight category. These robots had 4-wheel drive and 4-wheel independent-suspension Ackermann steering. These robots were integrated with on-board sensors and data loggers to record signals from 3D accelerometers, current and voltage meters, and wheel encoders. They were used extensively to collect mobility and trafficability data for extreme maneuvers on a wide variety of terrain types, including plowed fields, rock piles, sand pits, snow and ice. Data collected with these robots were the basis for a number of TRML publications. Over their four years of service both suffered repeated damage and repair. Ultimately, both failed, due to unreparable fracture damage to the main drive.

We fabricated and delivered one heavy-weight instrumented trailer to measure vehicle-terrain trafficability characteristics. The trailer was not robotic, but was designed to match the specific tires and tire loading of the Demo III Experimental Unmanned Vehicle (750 pounds per wheel). The trailer operated in two modes: with wheels locked and free rolling. The trailer was instrumented to measure drawbar pull with a load cell at the hitch, vertical acceleration with a one-dimensional accelerometer at the axle, and position with a differential GPS unit at the axle. The towed system reports speed, vertical disturbance, and resistance. When the wheels are unlocked, resistance is the rolling resistance. When the wheels are locked, resistance is sliding resistance. From these data, we can estimate maximum acceleration, drawbar pull, maximum speed, stopping distance, and disturbance as function of ground speed. The trailer was used in the terrain trafficability characterization at Toole Army Depot and at Fort Indiantowngap Demo III exercises.

3.3 On-Board Instrumentation

We delivered a variety of instruments for on-board sensing. The specific items were coordinated with the TARDEC engineers and scientists who would be using the equipment. Most of these items were integrated with specific mobile robots.

We delivered cameras, sonar sensors, bump sensors, IR sensors, inertial sensors, and wheel encoders fully integrated with the Pioneer 2AT and Koloa mobile robots before delivery. One of the Pioneer 2AT robots was also equipped with an inertial sensor and rate gyro system with navigation software. The Ackermann-steer robots with 4-wheel independent suspension were integrated with on-board sensors and data loggers to record signals from 3D accelerometers, current and voltage meters, and wheel encoders (the MultiLog Pro data logger, sensors and PC software from Fourier Systems).

We delivered one long-wave IR mini-FLIR (Raytheon) for on-board use, and several different miniature video cameras. We delivered several different models of 2.4 GHz video transmitter-receiver pairs, all of which were compatible with both the mini-FLIR and the miniature video cameras. The cameras were suitable for dual use as on-board video sources and/or off-board surveillance. The video can be used for remote teleoperation in either mode. We also delivered Imperix video frame grabber PCMCIA cards compatible with the wireless video receiver for off-board data logging.

We delivered a Trimble GPS unit, accelerometers, and load cells with the Demo III vehicle-terrain interaction surrogate trailer.

We delivered one "Gamma Scout" radiation detector to sense and report gamma, alpha and beta rays. We delivered a Crossbow 6-DOF inertial measurement unit with Bluetooth wireless interface.

3.4 Off-Board Instrumentation

We delivered a variety of instruments for off-board sensing and data logging. The specific items were coordinated with the TARDEC engineers and scientists who would be using the equipment.

We delivered a set of instrumentation and associated software for off-board data collection. We delivered one data logger and analog-to-digital sensor interface produced by Vernier Scientifics, along with voltage sensors, current sensors, force sensors, and accelerometers. The data logger has a USB and RS232 interfaces to a PC. It is suitable for use as either an on-board or off-board data logger, and can operate as a multi-meter, an oscilloscope or a force and torque measurement system with its PC software.

We delivered two items for off-board video and thermal image data logging: one Raytheon PalmIR Pro thermal imager with 25mm and 50mm lenses, a long-wave infrared polarizing filter, and four narrow-band IR filters. We also delivered one Panasonic DVD video camera with 16x variable zoom.

We delivered one Rimik CP20 cone penetrometer, and one Clegg impact hammer (with 1 kg and 5 kg weights), both with PC interfaces and PC software. The cone penetrometer measures quasi-static soil stiffness. The Clegg impact hammer measures dynamic soil stiffness. Both instruments were used to take terrain measurements in support of Demo III field mobility and terrain effects studies.

We delivered two data acquisition and logging computers for wireless in-lab and mobile use. These were a Fujitsu P600 tablet computer and a CF-72 Panasonic Toughbook laptop. The Fujitsu tablet computer is suitable for multiple uses: as a wireless operator console, as a remote data logger, and as an on-board data logger. We delivered an analog-to-digital PCMCIA frame grabber card (VCE-PRO, by Imperix) to digitize NTSC video at 30 Hz, with its software to run on either data logging computer. Both data logging computers were compatible with the Vernier data logger and analog-to-digital sensor interface. We delivered five Orinoco wireless interface cards (3 with USB interface and 2 with PCMCIA interface). After four years of field use as a data logger and robot control system in conditions ranging from blizzard at Fort Indiantowngap, PA, to desert summer at Toole Army Depot in UT, to all-season use in MI, the motherboard in the Panasonic Toughbook failed catastrophically.

3.5 Data Analysis, Simulation and Visualization Computer Systems

We delivered software for modeling, simulation and analysis of vehicle dynamics and robot controls, and hardware and software components for human interface virtual reality telepresence and teleoperation research and engineering. The specific items were selected in coordination with the TARDEC scientists and engineers who would be using the software.

The following software packages for modeling, simulation and analysis of vehicle dynamics and robot controls were delivered:

- WebBots robot simulation software
- SysQuake vehicle dynamics analysis software
- Rationale Rose visual configuration management software
- SimCreator graphical simulation and modeling software
- Visilog Pro image analysis software
- Microsoft Development Studio software development environment
- Matlab and Simulink with Control and Signal Processing toolboxes.

We delivered the "Open GVS" software package for 3D tele-presence interface development, and virtual reality simulation. We delivered the "LabView" software for hardware interfaces, signal processing and visual human interfaces. We delivered one pair of video and computer display goggles. We delivered two 42-inch plasma display systems with stands, video cards and controls for immersive tele-presence (with dual use as displays for briefings and presentations).